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FINAL REPORT

LORAN-C PERFORMANCE ASSURANCE ASSESSMENT PROGRAM

P- 36

Potential problems affecting Loran-C instrument approach use were identified, followed by investigation, measurement and analysis as required. Recommendations were made, and coordinated with the appropriate FAA and Coast Guard representatives.

by

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TABLE OF CONTENTS

LIST OF FIGURES

FOREWORD

This report is a collection of materials which were produced during the Loran-C Performance Assurance Assessment program, supported by NASA Langley Research Center under grant NAG 1-816. The work is the first phase of an effort which was continued by the Federal Aviation Administration (FAA) using other contract agreements. These materials were delivered to the FAA as required by action items issued by the Loran-C Program Office from time to time.

1.0 INTRODUCTION

The Federal Aviation Administration (FAA) has accepted the Loran-C navigation system as a supplemental navigation aid for enroute use. Extension of Loran-C utilization to instrument approaches requires establishment of a process by which the current level of performance of the system is always known by the pilot. This system "integrity" translates into confidence that, if the system is made available to the pilot, the guidance will be correct.

Early in the consideration of Loran-C for instrument approaches, the Loran-C Planning Work-Group (LPW) was formed with membership from FAA, the US Coast Guard, various state governments, aviation users, equipment manufacturers and technical experts. The group was hosted and co-chaired by the National Association of State Aviation Officials (NASAO). This forum was ideal for identification of system integrity issues and for finding the correct process for their resolution. Additionally, the Wild Goose Association (WGA), which is the international Loran-C technical and user forum, regularly brings together members of the FAA, Coast Guard and the scientific community. Papers and discussions from WGA meetings have been helpful.

This report contains a collection of the issues in which Ohio University became involved. Issues definition and resolution are included along with recommendations in those areas where resolution is not yet complete.

2.0 PROGRAM DESCRIPTION

2.1 FAA Ground Monitoring of Loran-C

Prior to the start of this assessment program, FAA contracted for Loran-C ground monitor equipment [1, 2]. Originally, it was thought these "monitors," placed nationwide at existing FAA VHF Omni-Range (VOR) transmitter sites, would be part of the Loran-C monitoring loop. In this mode, the ground system would trigger a flag in the aircraft or render the Loran-C signal unusable or absent when observed guidance signals were outside a specified tolerance. Studies of signal stability [3, 4, 5, 6] and the agreement by the Coast Guard to implement a closed-loop automated "blink" or flag capability at Loran-C transmitters removed the need for far-field executive monitoring, simplifying the system integrity loop considerably.

Once it became clear that nationwide closed-loop monitoring was unnecessary, the monitors became data collectors, responsible for gathering input for the National Field Office for Loran Data Support (NFOLDS) so that predicted corrections would be available for publication with Loran-C approach plates. Communications problems persisted at this writing, in the interface between the Loran-C monitor and the VOR remote maintenance monitoring network. [Work is proceeding to resolve this issue, between FAA and its contractor.]

The evolution of multi-sensor avionics including Loran-C and other systems, and the development of multi-chain Loran-C receivers is causing pressure for a software change in the FAA monitors, so that corrections can be available for multiple Loran-C chains, or multiple triads within a transmitter chain. The necessity for this change should continue in debate. The outcome is uncertain, because GPS calibration of Loran-C, and various architectures involving the use of the two systems as hybrid partners, may change the NFOLDS network's role in the future.

For site surveys of Loran-C signal characteristics prior to commissioning an instrument approach, FAA contracted for the Loran-C Site Evaluation System (LSES). A necessary part of the preparation for an instrument approach, the LSES does not perform complete checks on the signal quality which guarantee the signal meets the specifications against which receivers are required to be tested (Technical Standard Order C-60b) [7]. The argument against the need for such testing is that Loran-C signals are required to be strong before use for approaches in an area will even be considered, and that with a strong signal (i.e. a user relatively close to the transmitter) pulse distortion which could cause a receiver problem will not occur. This is plausible, but not proven. More details are given in the next sections of this report.

2.2 FAA Flight Inspection Procedures and Equipment

Initial program activities consisted of a series of meetings with FAA Aviation Standards National Field Office (AVN) personnel, to assess plans for flight inspection of Loran-C instrument approaches. It quickly became evident that Loran-C performance assurance problems did not center on general flight inspection policy or practice.

The FAA's current methods for instrument approach commissioning and periodic inspection all apply to Loran-C; the best comparison is with existing RNAV approaches, which use VOR and DME as navigation systems. To provide guidance to its flight-inspection crewson the specific differences between evaluation of Loran-C and VOR/DME RNAV approaches, FAA produced a new section for the US Flight Inspection Manual [8].

During the preparation of this document, FAA sought and received comment from members of the LPW. It recognizes that the Loran-C signal is provided by the US Coast Guard and that there is minimal opportunity for fine-tuning this wide-area signal at a specific location. It is considered likely that a failure to pass a periodic flight check will be due to local noise sources, which must be tracked down by FAA technicians in cooperation with local aviation authorities, in the same way as interference to FAA-owned navaids is isolated.

The specific equipment available for Loran-C flight evaluation requires careful study to resolve uncertainties in the receiver's measurement of signal quality and signal versus noise quantities. FAA personnel have discussed this issue at LPW sessions, and the agency has asked its Technical Center to help characterize the receiver.

As soon as equipment became available, FAA established a monitor equipment training facility at its Aeronautical Center at Oklahoma City. A complete training course was created for technicians with responsibility for the NFOLDS monitors [9, 10, 11, 12]. NFOLDS operational responsibility was assigned to the existing FAA data branch at Oklahoma City, again utilizing existing structures as Loran-C was introduced within the agency.

FAA produced three video tapes during the period of this program, two of these at the urging of the LPW education committee. Subject matter includes Loran-C basics, receiver certification requirements and user education on proper use of Loran-C equipment during approaches. Recommendations have been given to FAA that Loran-C material be included in accident prevention seminars; this has been done in some FAA regions, reportedly successfully.

Through the FAA meetings and through participation with FAA in the LPW process, a list of specific Loran-C performance-assurance issues was prepared. The role of the Ohio University program became one of being certain that the key issues remained visible until resolved. The list, which is the subject of the next section of this report, appears far broader than the initial focus of this program on flight and ground monitoring. Each issue represents a potential hazard which must be managed in a total system performance assurance program.

3.0 LORAN-C SYSTEM PERFORMANCE ASSURANCE ISSUES

As the Loran-C instrument approach program proceeded, several technical and procedural issues were raised. For each, action items were assigned, responses were provided to the FAA Loran-C Program Office, AND-30 and ultimately the issues plus data and recommendations were handed off to the appropriate existing FAA element for implementation. The result was a nearly agency-wide involvement in the Loran-C program.

3.1 Circle of Exclusion Around Transmitters

[This material was sent to the FAA Loran-C Program Office as a recommendation.]

The signal strength exclusion zone around Loran-C transmitters should be revised from the present fixed 30-nmi radius to a radius determined by transmitter power. The high signal strength exclusion zone near transmitters was established to insure that Loran-C receivers do not operate outside the test limits established in the Loran-C Minimum Operational Performance Standard by the Radio Technical Commission for Aeronautics (RTCA MOPS) [13] and Technical Standard Order (TSO) C60b. The test limit for signal strength (receiver dynamic range) is +110dB(uv/m).

At the Carolina Beach Loran-C transmitter, Ohio University carried out measurements and determined that +110dB(uv/m) is exceeded at distances closer than 43.7 nmi to the transmitting antenna.

With the installation of transmitters in the mid-continent region with 400-W power output, it seems unnecessary to impose the 1-MW Carolina Beach criterion near these lower-power sites.

Figure 1 shows a graph containing the field strength versus distance for a family of transmitter power levels (scaled from the Carolina Beach measurements). It is recommended that this data be used to determine the radius of the exclusion circle at each transmitter [14].

3.2 After-Accident Check Procedures

[This material was sent to the FAA Loran-C Program Office as a recommended after-accident check procedure.]

3.2.1 General

The Loran-C after accident procedures described in this section consist of only those specific additions and changes required for accommodating the differences which are unique to Loran-C navigation.

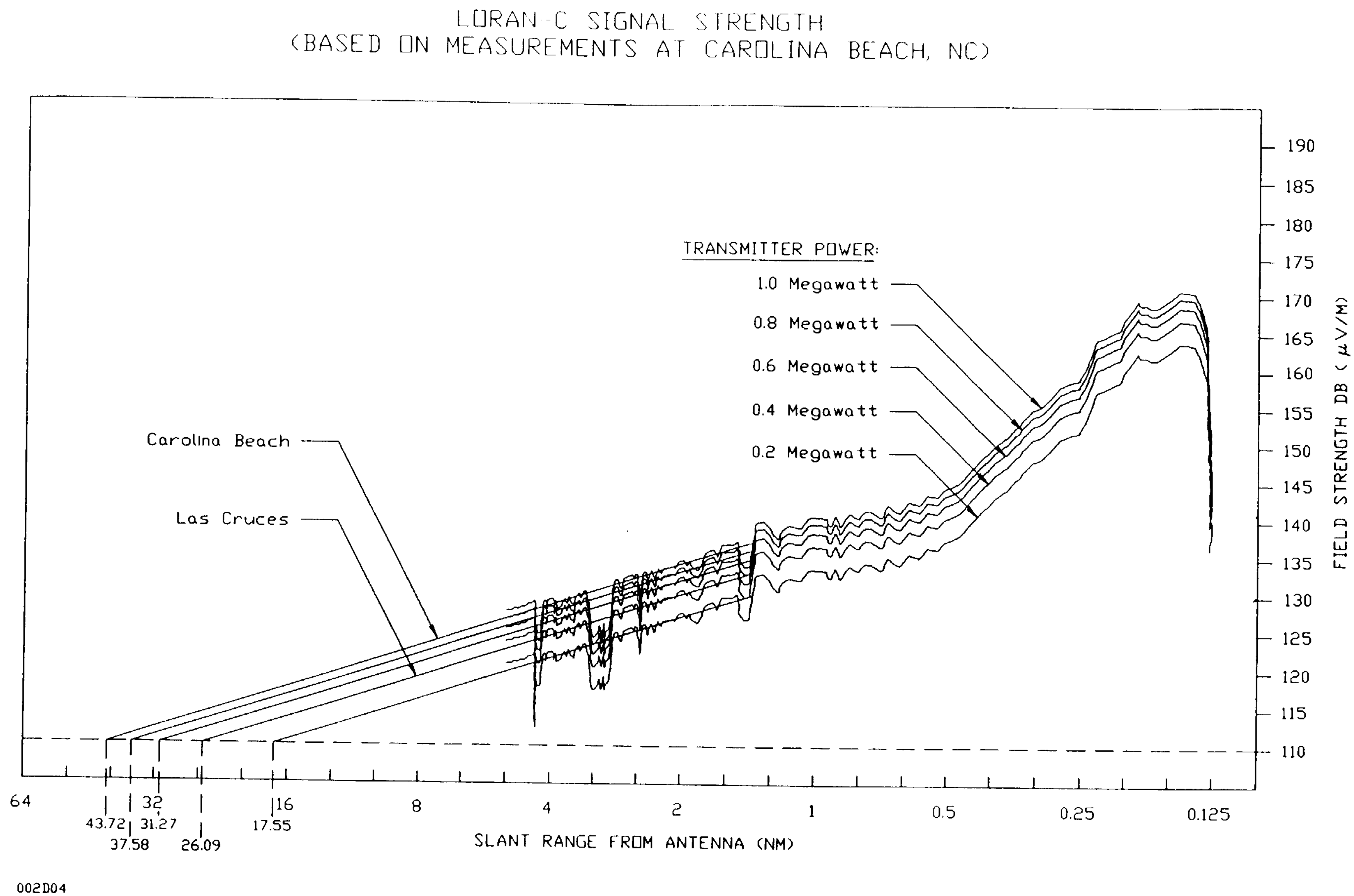

Figure 1. Loran-C Field Strength vs: Distance

Loran-C is a long-range earth-referenced radio navigation system, operated and maintained in the US by the United States Coast Guard (USCG). The Loran-C geographic reference system, signal propagation characteristics, and non-FAA management of the transmitter network make Loran-C fundamentally different from other air radio navigation systems in use today. Many of these characteristics are, however, also common to the forthcoming Global Positioning System. Therefore, procedures developed for Loran-C will also set precedents for future navigation systems.

3.2.2 Local Area Monitors

The Federal Aviation Administration has deployed its own array of Local Area Monitors (LAMs), throughout the country. The term "monitor" is somewhat different from the traditional FAA definition, in that the LAMs do not operate in a real-time executive mode except during the Early Implementation Program (EIP) [15]). Rather, they are serving two roles:

First, the LAMs act as data collectors for the FAA's NFOLDS Loran-C data base activity. Second, they are serving to generate Notices to Airmen (NOTAMs), from status information sent through the FAA's Remote Maintenance Monitoring System (RMMS). NOTAMs require time to pass through the various RMMS communication nodes, and are therefore not a real time function.

3.2.3 Memorandum of Agreement

In addition to the existing material requiring modification, it is necessary to expand the letter of agreement between the FAA and the USCG to include after-accident procedures, defining responsibilities, indicating communications channels, and dividing liabilities [16].

3.2.4 Loran-Specific After-Accident Activities - Discussion

The typical train of events following an aviation accident begins with Air Traffic Control (ATC) being made aware of the accident and notifying the Airway Facilities (AF) Manager. This notification includes information about the possible or probable involvement of navaids. The Airway Facilities Manager would then issue appropriate warning NOTAMs for any navaids likely to be involved, until those navaids can be checked. This is standard procedure, and does not differ in the event that Loran-C may be one of the navaids involved, except to the extent that the USCG, not the FAA, would have the responsibility for checking the Loran transmitting system.

Possible Loran-C involvement will, however, trigger an additional sequence of events. If Loran-C is potentially involved in the accident, the Coast Guard must be notified.

3.2.5 United States Coast Guard

The Airways Facilities manager shall, upon learning of possible Loran-C involvement in an accident, immediately notify the Coast Guard of the situation. For the most rapid response, the notification shall be made directly to the USCG contact by telephone or telex, and this should be followed by a formal letter of notification and request for an after accident report.

The impact that aviation use has on the Coast Guard's procedures is affected by the implementation of automated blink. This is simply an automated actuation of Loran-C signal coding, based on aviation-specific tolerances, intended to warn users that Loran-C signals are below aviation standards as measured at the transmitter. As a result, the Coast Guard's standard after-accident procedure would be modified only to the extent that aviation blink is taken into account. The results of the USCG investigation, in addition to their standard disposition, are to be reported directly and immediately to the FAA Investigator in Charge.

3.2.6 FAA Investigator in Charge (IIC)

The role of the accident investigator is not unique to Loran-C except for the use of the Coast Guard investigation results and for any possible communications that may be required with the Coast Guard. The IIC should check the aircraft involved in the accident for the presence of the current Loran-C approach plate(s), if Loran-C was involved or suspected in an accident. Loran-C time difference corrections are published every fifty-six days in the approach plate booklet, and are necessary for approach use. Also, to the extent possible, the IIC should determine the "settings" on the Loran-C receiver in the aircraft if appropriate, to determine if it appears that Loran-C was being used, and if so, that it was being used properly. In many cases, this determination may require manufacturer tests to recover receiver memory contents.

The following sections contain specific recommendations for document changes to implement the Loran-C after-accident process:

3.2.7 Documents Description

Several FAA and Coast Guard documents establish the after-accident/incident process. It is recommended that some of these documents be modified to include the unique characteristics of Loran-C when used in aviation.

FAA accident and incident notification, investigation and reporting procedures are established by Order 8020.11 [17], and supplemental guidance is provided by Regional Orders (see for example [18]) and Handbooks (see [19]). General equipment maintenance and certification procedures are contained in Order 6000.15 [20], and specific Orders exist for individual NAS elements. For example, the FAA NFOLDS Loran-C sensor equipment (also referred to as the Local Area Monitor, or LAM) is certified according to procedures contained in Order 6860.2 [21]. The U. S. Standard Flight Inspection Manual, Section 209 [8] and Order 8240.36C [22] on flight inspection reporting procedures give the necessary guidance for after-accident flight inspections, when required.

U. S. Coast Guard publishes the Aids to Navigation Manual [23], which establishes operating, maintenance, casualty-recovery and reporting procedures applicable to Loran-C system management by the Coast Guard.

The document outlining the interagency agreement between the FAA and the Coast Guard is the Memorandum of Agreement [16] which sets forth the duties and responsibilities of the two agencies and their respective liaison personnel.

During the Loran-C Early Implementation Program for instrument approaches, FAA produced a Performance Validation Handbook [15] for the real-time monitors used in this program. This Handbook remains in force until the permanent NFOLDS Loran-C sensor network and the automated transmitter monitors are fully operational.

3.2.8 Recommended Document Changes

3.2.8.1 Order 8020.11: Accident/Incident Reporting

3.2.8.1.1 Chapter 4, Section 1, paragraph 89; Duties of the FAA IIC

> In a.(1) of this paragraph, insert "... non-FAA providers of navigation aids identified by the regional AFD Accident Representative (see paragraph 157)..."

3.2.8.1.2 Chapter 4, Section 6, paragraph 157; Duties of the Regional AFD Representative

> After item h, add a new item i to read "Recommend to the FAA IIC that non-FAA providers of navigation aids identified in paragraph 157d be notified and that such providers prepare appropriate documentation of operational status of the navigation aid for submittal to the FAA IIC, as specified in the applicable memorandum or letter of agreement."
>
> [This change recognizes that Loran-C is a non-FAA system, and that the Coast Guard must be notified after an accident or incident where Loran-C may be a factor.]

3.2.8.2 Regional AF 8000-series orders:

The Eastern Region Order [18] used as an example does not require modification. Regions should be notified of the above changes to Order 8020.11 and urged to review the appropriate regional Orders and update these to reflect the Coast Guard notification procedures and points of contact for Loran-C after-accident matters.

3.2.8.3 FAA Order 6000.15: General Maintenance Handbook

No change is required.

3.2.8.4 FAA Order 6860.2: Maintenance of Loran-C Monitors
Chapter 1, Section 3; Aircraft Accident

> In paragraph f, replace the words "...relative to shutdown and flight inspection requirements" with "...relative to monitor status, NOTAM issuance and notification of AVN-250."

It is important for the IIC to notify AVN-250 to arrange for capture of the input data for the current published Loran-C corrections at the accident site, if Loran-C is a potential factor in the accident/incident.

The Loran-C sensor is a certified piece of equipment due to its use in the NAS as a source of NOTAMs on the status of the Loran-C system. It may provide information on after-accident signal status, but it is important to recognize that this is a data-collection sensor, and not an executive monitor. It may be located up to 90 nmi from the accident site. The pilot of the aircraft depends upon his on-board avionics and on Loran-C transmitter monitors for warning flags. The NFOLDS sensor units provide long-term data to AVN-250, which prepares correction data tables published with the approach charts.

3.2.8.5 U. S. Standard Flight Inspection Manual, Sections 104 and 209

3.2.8.5.1 Paragraph 104.51; After Accident

> Comment: Item c(4) refers to executive monitors installed on FAA navigation aids. The Loran-C "monitor" is not an executive monitor. Recertification of the Loran-C sensor by AAF after an accident assures accurate NOTAM source information. No change is required in item c(4).

3.2.8.5.2 Paragraph 209.21; Preflight Requirements, Ground Personnel

> In item b, note that the Loran-C NFOLDS sensor ("monitor") is called a LAM, or Local Area Monitor. It is recommended that the following sentence be added to item b:
>
> "LAM information is useful as a reference during a flight inspection, but out-of-tolerance LAM data does not invalidate an otherwise successful flight inspection."

3.2.8.6 FAA Order 8240.36C: Flight Inspection Reporting

No change is required in this document. The appropriate forms and procedures for Loran-C have been added previously.

3.2.8.7 Coast Guard Aids to Navigation Manual

Chapter 2, Section E: Reports and Notices

> It is recommended that a paragraph be added to this section specifying the response required when the Chain Operations Commander (COCO) or station personnel are notified of an aircraft accident where the Loran-C chain may be a factor. This response should include a statement of the status, at the time of the accident, of stations serving the area where the accident occurred, and capture of operating parameters.
>
> Further, a paragraph should be added which prohibits changes to the transmitters prior to FAA's after-accident flight inspection and recertification of the Loran-C sensor ("monitor") serving the accident area.

3.2.8.8 FAA/USCG Memorandum of Agreement, March 1986

In order to provide for investigative detail and timeliness comparable to after-accident procedures for other FAA navigation systems, it is recommended that this Memorandum be updated to provide:

3.2.8.8.1 A single point of contact at the Coast Guard for after-accident notification (likely the Loran Management Branch at USCG Headquarters, Washington). Delineate the proper channel for subsequent coordination between Coast Guard operations personnel and the FAA Investigator in Charge (IIC).

3.2.8.8.2 Specification of after-accident data required by FAA, and appropriate reporting forms, including:

- Transmitter monitored parameters
- Status of "automated blink" subsystem
- Status of SAM
- Status of SAM and ROS communications

3.2.8.8.3 Specification of after-accident operations:

- Transmitter data to be captured within 24 hours, and submitted to the FAA IIC within one week.

- Transmitters not to be adjusted after initial after-accident notification without informing the IIC, until the IIC notifies the Coast Guard that FAA certification and after-accident flight inspection, if required, are complete. This period is expected to be approximately 24 hours in most cases.

- Coast Guard to record any system deviations during FAA certification and after-accident flight check activities, and submit data to the FAA IIC.

3.2.8.8.4 Delineation of reporting points and channels of coordination among FAA, Coast Guard and NTSB investigators, should the Board investigate the accident/incident.

3.3 <u>Receiver Check Procedures</u>

[In the time since these procedures were prepared and submitted to the FAA, some tests may have been supplanted by receiver self-test functions.]

3.3.1 Background

A procedure is required to verify the function of the airborne LORAN-C receiver similar to the monthly test procedure currently used for the airborne VOR receiver. VOR receivers are required to be tested by:

a. tuning a VOR Test frequency (VOT) when available, or
b. using ground or airborne VOR check points or
c. checking one VOR receiver against another in the aircraft, and verifying that the VOR indication is as prescribed.

This test is to be performed within thirty days of using the equipment for IFR flight.

This proposed loran receiver test procedure is analogous to the VOR test, but since the information provided by the receiver and its user interface are different from those associated with the VOR receiver, the test differs from the VOR test. The objectives are, however, the same.

3.3.2 Loran Receiver Test Procedure

The loran receiver must be checked using this procedure within thirty days prior to using the equipment for a loran instrument approach. (Internal receiver self-tests should also be used frequently, to demonstrate correct operation of the processor and display functions, but these self-tests are not sufficient to meet the requirements of this test procedure.) The Receiver Test may be performed by any of the means prescribed below:

3.3.2.1 Laboratory

The loran receiver may be tested in a laboratory or repair station environment by either:

3.3.2.1.1 Inserting signals from a loran simulator (signal generator); a geodetic position fix must be obtained from the receiver which coincides with the generated position within ± 0.40 minutes in both latitude and longitude.

3.3.2.1.2 Obtaining a position fix from the loran receiver in the laboratory corresponding to a designated laboratory position fix (surveyed to an accuracy equal to that of airport geodetic position reference points) which coincides with the reference position within ± 0.40 minutes in both latitude and longitude.

3.3.2.2 On the Ground

The aircraft shall be taxied to a designated airport geodetic ground reference point. The position indicated by the receiver must correspond to the surveyed position within ±0.40 minutes in both latitude and longitude. If the designated ground check point is defined in angle and distance from a VOR station, the loran receiver may be checked by inserting the VOR station as a waypoint, and verifying that the indicated bearing is within ±4 degrees and distance is within 0.4 nmi.

It is recommended that the airport geodetic ground reference points be included in the loran receiver data base, to simplify the test for the pilot.

3.3.2.3 In the Air

For situations where it is infeasible or inconvenient to position the aircraft at a geodetic ground reference point within thirty days prior to making a loran instrument approach, the test can be performed in the air.

[Note that a test performed in the air will yield a lower confidence than a test performed on the airport or in the laboratory.]

The fix can be performed by comparing the loran position to an independently established position as described previously, in any of four ways:

a. Comparison with an RNAV fix, based on VOR and DME. Fix bearing must agree to within ±4 degrees and distance to within 0.4 nmi.

b. Comparison with a position fix defined by separate VOR and DME systems. Bearing must agree to within ±4 degrees and distance to ±0.4 nmi.

c. Comparison with position as defined by two radials from independent VORs. Each VOR waypoint checked must generate a loran bearing which agrees with the VOR bearing within ±4 degrees.

d. By comparing simultaneous fixes developed by two on-board loran receivers at a given point in space. They must agree to within ±6 degrees bearing and 0.6 nmi distance, to a common waypoint.

Note that it is considered prudent, but not required, to establish additional confidence in correct loran receiver operation by one of these airborne methods during the period immediately prior to beginning a loran instrument approach.

3.4 Power Line Carrier Interference

[FAA approach designers have adopted a criterion which keeps instrument approach paths a safe distance from PLC-active transmission lines. PLCs are still considered a potential threat to low-frequency navigation.]

Initial work done by NTIA and others [24,25] established the concern for power-line carrier (PLC) interference to Loran-C receivers. Originally thought to be an action item for the LPW group, the PLC concern has been followed up by Coast Guard and FAA representatives.

FAA Spectrum Management (ASM-500) has been working for a Federal Communications Commission (FCC) restriction of the 90-120 kHz band to navigation only, in contrast to the present non-interference permission granted to PLC users. The Coast Guard also supports this position.

The FCC, however, recently has turned down a USCG/FAA Petition for Reconsideration [26] which asked for removal of PLCs from the Loran-C band. Work continues, in an attempt to make the case that PLCs in the Loran-C navigation band are dangerous.

To provide data on existing PLC operations, the Coast Guard and FAA use a data base of PLCs together with a search program [27]. The data base is produced by the North American Electric Reliability Council [28].

3.5 Precipitation Static Problems

> [FAA has recently expressed interest in video-tape presentations on p-static problems, as educational materials for the pilot and the avionics installer.]

Airframe-generated electrical noise has caused problems for users, for FAA aircraft and for manufacturers during avionics certification flights. Note that the term "p-static" has been used to describe the overall problem, but p-static is only one element [29,30].

P-static charging may be present, in general, only when the aircraft is moving through particles. The impact with these particles causes static charging of the airframe, in the same way that scuffing the carpet and touching a doorknob sometimes reveals static charge. Cloud droplets can cause this, as can rain, ice or snow. In general, snow causes rapid charging. Charge can also be imparted to the airframe as it travels through areas of strong charge separation, as in the vicinity of thunderstorms.

The presence of charging itself apparently does not cause significant radio noise. Interference is caused as the charge leaves the airframe via ions in the slipstream, or migrates from place to place on the airframe. The energy and frequency of these discharges is dependent upon airframe shape and condition, and upon the presence or absence of discharger devices.

There are three principal noise sources:

3.5.1 Corona discharge

Corona discharges take the form of pulses of energy (packets of ions) which leave the airframe most readily from small-radius points. Their energy level is generally determined by the airframe geometry, and the pulse repetition rate is determined by the amount of charge on the airframe. This interference is heard as a hiss (in the ADF receiver, for example). If enough energy is generated in the loran passband, this interference reduces the receiver's ability to "hear" the loran signal.

Many antennas are designed with coatings designed to minimize static discharge. These will only work if a good bond is maintained with the airframe.

To minimize corona, place static dischargers designed for low-frequency protection at points recommended by the airframe manufacturer. Keep the dischargers maintained! They can be "burned out" by very strong charging or a close encounter with lightning. They may also be broken mechanically.

3.5.2 Streamering on non-conductive airframe surfaces

Charge separation on the airframe may cause "streamers" to appear on windscreens, radomes or other nonmetallic airframe components. Some manufacturers embed metal or coat such components to minimize streamering by giving a conductive path for charge-generated currents.

Streamering is generally of shorter duration than corona discharges, but may be more energetic.

3.5.3 Arcing between airframe sections

As charge accumulates on an airframe, very high voltages are produced. If, due to corrosion, lack of proper grounding straps or imperfect bonding between airframe components (including antennas), there are non-conducting areas on the aircraft, the voltage build-up will likely not be uniform. Arcing may then occur across the gaps.

Again, the arc is of short duration, but contains very high energy (can produce much noise). Enough of these arcs can cause significant interference. The solution is to keep the aircraft clean, eliminate corrosion and loose bonds, and be sure the antenna installation is kept in good condition and to manufacturer's specifications.

Maintenance-related noise sources are such items as loose nav-light wires, loose or corroded or dirty antenna connections, water invasion of connectors and bad DC-power filters. Loran-C users must recognize its sensitivity to noise and must maintain the overall airframe carefully.

These noise problems can be very elusive, and one is tempted to conclude that "black art" is required for solution. Test equipment and procedures are available to FBOs and manufacturers to maintain the fleet, but improvements are needed.

The manufacturer, installer and user of all types of aircraft equipment and accessories must be aware of the symptoms, and the techniques for minimizing these sources of interference. While the noise so generated can affect other navigation systems and even VHF communications in severe cases, Loran-C is especially vulnerable due to its low frequency of operation.

It is worth noting that Omega navigation operates successfully at even a lower frequency, but these systems often use magnetic-field (loop) antennas, which are somewhat less sensitive to these forms of airframe-generated noise. Care is still required in Omega antenna location, however, since it is sensitive to skin currents on the airframe as charge migrates.

3.6 Loran Site Evaluation System

[The LSES is currently under development by FAA. Recommendations were submitted after the Preliminary and Critical Design Reviews.]

The project team followed the development of the Loran Site Evaluation System (LSES) through Critical Design Review (CDR) [31], which was held on November 8, 1990. The LSES design provides for appropriate measurements of all but one of the necessary Loran-C signal characteristics for the screening of airport sites.

The loran receiver chosen for LSES appears to permit observation of loran pulse quality, but the LSES processing software being developed does not recover these observations. The receiver manufacturer reported at CDR that cross-correlation of the received pulse with an idealized pulse model results in a "figure of merit" which is sensitive to the pulse shape of the received signal.

The elements of pulse quality include envelope-to-cycle delay (ECD), skywave interference and signal-to-noise ratio. ECD and skywave effects are difficult to measure in moving flight-inspection aircraft. Therefore, the (stationary) LSES provides an appropriate platform and is the only opportunity to determine that the signal in space falls within TSO C60b [7] test limits.

The project team recommended to FAA that appropriate tests be conducted by the FAA Technical Center to determine the degree to which the receiver correlation outputs are sensitive to TSO C60b signal test parameters, and to place tolerances on the correlation values. Further, the team recommended that the LSES design be expanded to include this observation of pulse quality, if the FAATC tests are successful.

See the Pulse Quality Measurement section of this report for additional details on the need for these measurements.

3.7 Loran-C Pulse-Quality Measurement

[These pulse-quality measurement recommendations were prepared during LPW meetings and were submitted through NASAO to the FAA Loran-C Program Office, AND-30.]

Measurement of the quality of the Loran-C signal in space is necessary to guarantee that the signals available to user receivers comply with the test limits imposed by TSO C60b. The functions of the Loran-C Site Evaluation System should be expanded to include these measurements, and appropriate tolerances should be developed. Suggestions for implementation of these recommendations are included.

In order to insure predictable operation of any navigation system, its components must be operated in known states. The range over which valid and predictable operation is to be guaranteed is specified during system design and is demonstrated in the field through testing. The term "performance space" is coined for use in this section, meaning the multidimensional region bounded by a group of navigational signal parameter limits.

For instrument-approach use of a Loran-C receiver, this performance space is defined by the RTCA MOPS [13], as modified by the TSO C60b [7]. The MOPS and TSO specifications and test designs were based upon knowledge of the characteristics of the Loran-C signal and on navigational accuracy and reliability requirements of the National Airspace System (NAS).

For aviation use of the Loran-C transmitting systems, signal-in-space quality is maintained by transmitter monitors and verified by the Loran-C Site Evaluation System (LSES) during instrument approach development. Flyability and safety of the resulting instrument approach are certified during FAA flight inspections. At some point in the process, all signal parameters which define the performance space must be measured. Each must fall within its range of values used in MOPS/TSO test design, so that these tests are valid predictors of receiver performance in the airspace.

This obviously circular process results in a single rule: Both the receiver and the signal-in-space must always operate within the performance space over which the receiver was tested. If either departs from this space, results cannot be guaranteed, and provisions must be in place to warn the user.

3.7.1 The MOPS/TSO Performance Space Parameters

Signal parameters are:

- Group Repetition Interval (GRI) for Loran-C chain to be used
- Strength of atmospheric noise
- Strength of any cross-rate signals present
- Frequencies of continuous-wave (CW) interferers
- Strengths of CW interferers' signals

and, for each of the three Loran-C signals (the triad) specified for the instrument approach:

- Signal strength
- Delay of the skywave with respect to the groundwave
- Strength of the skywave signal
- Envelope-to-Cycle Difference (ECD) value

The chain GRI is measured by the receiver directly, and the strength of the desired Loran-C signals and atmospheric noise are measured either directly, or indirectly as signal-to-noise ratio (SNR). These values are also validated (screened) during LSES measurements and during flight inspections.

> [Note that for the SNR or signal strength process to work, agreed-upon standards for low-frequency atmospheric noise must exist.]

For multi-chain receivers, at least a portion of the cross-rate interference is converted into "desired" or "accommodated" signals by the processor. For single-chain receivers, cross-rate signals are indeed a form of noise. In either case, the resulting SNR values reflect the presence of this form of interference.

CW interference is either notch-filtered or processed, and the result is reflected in the SNR values, which are measured both by LSES and flight inspection operations. It is conceivable that a modulated interferer could have an effect on observed Loran-C pulse shape, but this effect would be of short duration and not likely to cause navigation errors.

The remaining elements bounding the Loran-C performance space are ECD and skywave distortion of the ideal pulse shape.

3.7.2 Envelope-to-Cycle Delay (ECD)

As the Loran-C pulses propagate, pulse shape changes in a reasonably predictable fashion due to the differential in velocity of propagation among the frequency components of the signal. The principal parameters determining ECD at a given location are distance from the transmitter and the ground conductivity under the propagation path [32].

Predictions are useful for initial system coverage planning for location of transmitters and for preliminary screening of airport sites. Local variations must be measured to validate a particular site, since ground conductivity is not known in detail.

3.7.3 Skywaves

Skywaves distort the received pulse by recombining with the groundwave (desired) pulse after reflecting from the ionosphere. The height of the ionospheric layers is affected by the position of the sun and by solar flares and storms. When the ionospheric reflecting layers are at relatively low altitudes, the time delay between the received groundwave and skywave signals can be short, and the skywave can distort the early portions of the received pulse. This distortion can confuse the receiver as it attempts to acquire the proper tracking point on the pulse.

Receiver acquisition of an improper tracking point can cause very serious and unannunciated navigational errors, far in excess of the requirements for instrument approach accuracies.

3.7.4 TSO C60b and Pulse Distortion

The test suite given in Table 2-6 of the TSO [7] specifies the limits for ECD and skywave signal strength and delay over which the receiver must demonstrate correct performance. Since ECD and skywave interference change with location in ways which are partially predictable, the specification of system coverage provides some protection. System coverage limits were specified as part of the MOPS/TSO development process, and are part of the basis for TSO test limits.

It is the remaining, unpredictable, local variations in ECD and skywave distortion which require field measurements of the signal-in-space, in order to guarantee system integrity.

3.7.5 The Loran-C Site Evaluation System and Pulse Quality Measurement

The Trimble 10X Loran-C/GPS receiver has been chosen as the sensor for the Loran-C Site Evaluation System (LSES) [31]. This receiver measures the received pulses using methods which can extract the required pulse-quality information:

a. The Trimble receiver uses a pulse-quality measure to determine the tracking point. Trimble has an extensive "toolbox" of software routines which display various signal parameters on graphs and with tables.

b. The measurement of quality involves determination of ECD, noise and skywave effects. The Trimble 10X method should be sensitive to all three.

c. The use of Trimble's Fast Fourier Transform software may also permit recovery of components of the noise environment, providing a convenient spectrum-analysis capability without additional hardware. Airways Facilities and FAA Spectrum Management teams may appreciate this trouble-shooting tool.

d. The Trimble method is first to build a "reference" burst shape, based on an initial estimate of receiver position and including a predicted ECD value based on this position relative to each transmitter. The actual received signal is digitized immediately upon receipt, and the resulting samples are averaged to bring the Loran-C burst out of the noise.

   The averaged received burst is then repeatedly cross-correlated with the reference burst, with small offsets in time. These correlation coefficients, when graphed against offset value, produce a curve whose peak represents the best correlation. The third-cycle point on the reference burst, plus the offset, then represents the best tracking point.

> The value of the correlation at the peak is a "figure of merit" for the incoming burst. When this number is related to TSO test limits, a tolerance may be applied for LSES use.

This correlation method is a true measure of pulse characteristics, and the resulting data should not be Trimble-specific. Further discussion with Trimble may be necessary to define what notch filtering or other activity is done ahead of this correlation process, to be certain we have an "objective" measurement instrument.

Simulator testing of the 10X at the FAA Technical Center should be performed, to document the sensitivity of this correlation measure, its range and rate of change relative to the TSO performance space. Tolerances can then be developed.

If these tests succeed, the correlation figures should be added to the Trimble output data stream for use by the LSES.

3.7.6 FAA's Ability to Respond to User Complaints and Flight Inspection Results

Since ECD and skywave distortion are difficult or impossible to measure during a flight inspection, the function of the LSES may require expansion to that of a "Portable Loran-C Receiver," analogous to the "Portable ILS Receiver" (PIR) test equipment used by Airway Facilities.

In the face of a flight-inspection failure, persistent user complaints at a particular site, or as part of an after-accident investigation, FAA must have the capability to trouble-shoot and re-certify the approach procedure. All performance-space parameters must be measured, so that signal-in-space compliance with the TSO performance space may be determined.

The LSES, therefore, becomes a valuable tool for much more than just the pre-screening of a potential SIAP location.

3.8 Human Factors

> [The CDI scale-factor, identified as a human-factors issue and also as a TERPS issue, is being studied by FAA and DOT. As far as is known at this writing, the broader issue of receiver interface standardization is not being pursued.]

During the series of LPW meetings, a Loran-C human factors committee was formed. This group met several times, and produced a lexicon of terms and acronyms which was proposed to the FAA as a standard.

Relevant human factors issues include both those that are common to conventional air navigation systems and some issues that are either primarily relevant to all area- or random-navigation (RNAV) systems or that are specifically unique to Loran-C.

The issues that are common to conventional air navigational systems consist mostly of rudimentary control and display considerations. Examples of these are the size, style, color, lighting, drive algorithm, calibration, and configuration of the navigational display - the course deviation indicator (CDI), the omni bearing selector (OBS) and the associated controls and displays.

In addition, there are related concerns about the presentation and format of the supporting printed materials such as the charts and the approach plates. Examples of these human factors issues are the layout, size, presentation, color, contrast, diagram conventions, and fonts of the information on the page.

Loran has many human factors issues in common with conventional navigation systems in general, and with RNAV systems in particular. Loran receivers have outputs to drive standard CDI displays.

RNAV CDI operation for approach procedures may respond differently from those based upon the instrument landing system (ILS), or VOR. The first difference is that area navigation does not depend upon a transmitter located at the end of the runway. Therefore, the guidance to the runway need not be not angular with RNAV, but can be linear instead. The sensitivity of the CDI needle, and the accuracy of the guidance, does not increase with proximity to the runway threshold. The second difference is that the needle sensitivity need not be fixed with RNAV. It can be selectable, and "optimized."

There is a tradeoff between pilot workload and more precise guidance. Optimally balancing these two factors is the challenge. Also, there has been much debate over the relative merits of linear versus angular guidance and over the "optimum" needle sensitivity (or CDI "scale factor").

VOR plus distance-measuring equipment (DME) RNAV is based on the common "range and bearing to or from a station" convention (the rho-theta system of fixing position). Loran-C is known as an "earth referenced" system. Earth-referenced is a term used to indicate that the reference is not to a point on the earth, as in a rho-theta system, but rather to the earth's geoid as specified by the latitude and longitude (lat/lon) coordinate system. Prior to the advent of Loran-C and the Global Positioning System (GPS), virtually all of general aviation navigation was based on the rho-theta "station-referenced" system.

Loran and GPS use the lat/lon reference system for general aviation. This is an unfamiliar system for most general aviation pilots and many air traffic controllers. This is especially true since the lat/lon system coexists with the rho-theta system. The difficulty is exacerbated by a third system introduced by Loran - the "time difference" (TD). Loran fixes are determined by TD measurements made by the receiver. Correction factors or bias adjustments, applied either automatically or manually to an approach waypoint are presently specified and published in terms of the TD. Confusion results from a navigation system that employs three different "units" of measure.

Ultimately, a single standard unit of position such as lat/lon should be used. However, this is probably not practical as long as the rho-theta systems are in widespread use. Still, to the extent possible, the Loran system should be made functionally transparent to the pilot. A step in this direction is to remove the need for the TD unit. Fortunately, simply including approach corrections in the receiver data base will correct this.

All Loran receivers are designed to provide fixes in either the lat/lon or the rho-theta modes. Almost all airborne Loran receivers have internal databases which store the positions of standard waypoints, such as navaids, airports, and intersections. This simplifies the data management responsibilities for the pilot. It is the intention of the TSO C-60b, for Loran receivers, that those receivers to be approved for Loran approaches are to store and auto-sequence the waypoints for the approach as a single procedure. This reduces the opportunity for an error in data entry (blunder) and reduces the pilot workload.

The sheer volume of data needed, or data that are useful, is enormous. The more data that can be included in a database, the less likely is the opportunity for pilot error in putting in the data. An input error of only one digit can mean trouble. The incorporation of a comprehensive database places the pilot in an active supervisory role, instead of in a manual operator role. This reduces the possibility of a serious error.

There are human factors issues that go beyond those that affect the pilot directly. There are two prominent ATC issues related to the incorporation of widespread Loran use in the NAS. First, a difficulty with the lat/lon system is that it is not presently the "majority" system in ATC. Controllers are accustomed to providing communications using rho-theta terms. The incorporation of lat/lon thinking into ATC is no small task.

Second, VHF area navigation systems are in use now. They afford the capability of navigating directly between two points, even off airways. Since RNAVs are relatively rare, direct routing over long distances, off airways, is still not a routine practice. The frequent routing of aircraft in this fashion will take some adjustment by ATC.

Loran receiver operation and interpretation are considerably more complex than those required for any VHF system. There are no existing or proposed standards, for the design of the Loran receiver/pilot interface. In general, most receivers have navigation, flight planning, waypoint, and "system" modes. The menu functions and access to these modes and their associated functions are not standardized. It is challenging to operate a Loran receiver without becoming thoroughly familiar with the receiver manual (which itself may be confusing and lengthy). It is at least equally challenging to switch between one receiver and another.

Part of the difficulty with the receiver-pilot interface is that receiver panel and instrument panel "real estate" is at a premium. Manufacturers have all taken novel paths to accessing the many functions of a Loran receiver using few controls. The result is a small grouping of multi-function controls, each of which may perform several tasks within a hierarchy of menus - none of which is standardized.

Probably the most reasonable compromise is to divide the burden between some standardization of the receiver operation and some added requirements for training. Perhaps the present necessity for something like a "type rating" for each Loran receiver can be avoided.

Never before has so much navigation power been placed in the general aviation cockpit. Never before has so much confusion, and potential danger, been the result. Some argue that a prudent pilot would take the time to learn the proper operation of the receiver before takeoff. As more pilots use Loran in the IFR and the approach environments the exposure to risk will increase. It may well be that the time has come for some standardization of general aviation avionics equipment similar to ARINC standards for commercial aircraft.

An alternative to the pilot interface design standards is to impose training requirements/restrictions on pilots. In either case, it is essential to incorporate Loran familiarization and training into FAA pilot and controller training and testing.

3.9 Training and Education

> [FAA has produced three video tapes on Loran-C subjects, and has revised the Airman's Information Manual [33] Loran-C entry.]

Already in use for VFR and IFR enroute flying in the National Airspace System (NAS), Loran-C is about to become available for public use standard instrument approach procedures (SIAPs) for aircraft. This will complete the integration of Loran-C into the NAS as an instrument navigation system. However, it will also mean that Loran will be used for critical approach guidance near the ground.

Loran-C brings both more power and more complexity to the cockpit than the average pilot has ever faced. Used properly, loran affords more information and guidance than has been available. It is essential that pilots and air traffic controllers be trained and educated in the subtleties of Loran-C operation, so that they can take full advantage of the system while keeping the risk minimal.

It is crucial that a training program be implemented by the FAA, to disseminate information about the proper installation and operation of Loran-C airborne equipment. High-quality training materials are needed to inform aviators of Loran-C capabilities and limitations. FAA written and flight test materials must be updated to include Loran-C content.

The first public Loran-C approach procedures were published on November 15, 1990, but the procedures are unusable until the other components of the system are in place. The FAA training program should be in operation before the public begins to use the approaches. An appropriate channel for the program would be user forums presented periodically by local FAA accident prevention specialists.

The materials to be developed should include a LORAN-C Advisory Circular, an instructional video tape, and other supporting material necessary for the user forums.

3.9.1 Draft Advisory Circular on Loran-C Usage

An Advisory Circular would serve as the focus document for the FAA to disseminate basic Loran-C information. It would cover the principles of operation of the Loran-C system. This would include a brief history of Loran-C development, transmitter and chain selection, weather and propagation effects, the proper installation of Loran-C equipment in an aircraft, installation concerns, installation inspection and approval.

A section should include approach procedure familiarization, typical missed approach procedures and alternate-airport selection when using Loran-C.

Generic treatment of cockpit operations including data base management, receiver operation, receiver display and output interpretation.

3.9.2 Educational Video Tape(s) on Loran-C

As a companion and supplement to the Advisory Circular, the videotape series should cover the most important aspects of the Advisory Circular content, but would be slanted to a fast-paced and entertaining presentation. The tapes would be particularly useful to flight schools for pilot familiarization.

Additional video tapes would be useful to cover specific subjects. An example would be an instructional tape for airframe bonding and special static wick installation on an aircraft, to reduce or eliminate precipitation problems. This would be of primary use to avionics shops installing Loran-C receiver systems.

3.9.3 New Standards for Pilot Training and Evaluation

The use of conventional navigational systems is incorporated in present flight training and testing criteria. Loran-C-based navigation must be added, so that pilots are exposed to Loran-C training and evaluation as they are to the VOR, ILS, and NDB systems. Likewise, instrument pilots must be required to demonstrate Loran approach proficiency just as they are for the other approach types.

In addition to presentations at accident-prevention meetings, these materials could be used in the regions and at the FAA Academy for training FAA personnel. It is expected that the materials could be made available by the FAA or other organizations for sale to pilots for recurrent training, as are other materials.

There is good reason to focus on the training and educational requirements specifically for systems like Loran-C. Loran-C is an earth-referenced navigation system, fundamentally different from existing air navigation systems in its operation, data management, installation, and failure modes. There is a great variety in the configuration of receivers available, and as a result, there is variety in their operation not previously seen in the general aviation cockpit. Loran-C is not functionally transparent to the user as are the VOR, ILS, or NDB.

4.0 RECOMMENDATIONS

The Federal Aviation Administration should continue toward implementation of Loran-C instrument approach procedures. The system performance assurance issues recounted in this report are tractable, and each has been assigned to an appropriate group within FAA for resolution.

As discussed in this report, specific recommendations are:

a. Implement the circle of exclusion around each transmitter according to transmitter power and the receiver dynamic range given in TSO C60b.

b. Implement the proposed changes to existing after-accident procedures to take Loran-C into account.

c. Implement the receiver test procedure, or, if it is determined that receiver self-tests supplant this procedure, recommend the procedure to pilots as a supplemental integrity check prior to initiating a Loran-C approach.

d. Continue to press for removal of all potential interfering transmitters from the 90-120 kHz band, reserving this band for navigational signals only.

e. Produce and distribute detailed material on p-static and other forms of airframe-generated noise for pilots and maintenance personnel.

f. Either implement Loran-C pulse-quality measurement in the LSES units or determine through investigation and measurement that the Loran-C signal does not exceed the TSO C60b test limits, at the limits of coverage for instrument approach use.

g. Encourage industry standardization of Loran-C receiver functions and nomenclature, recognizing the increased operational complexity of these units over conventional navigation receivers.

h. Continue to produce and use Loran-C training and educational materials, and include earth-referenced navigational content in written and flight tests.

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VII. GLOSSARY

CDI	- Course Deviation Indicator
COCO	- Coordinator of Chain Operations
CW	- Continuous-Wave
DME	- Distance-Measuring Equipment
ECD	- Envelope-to-Cycle Difference
EIP	- Early Implementation (Loran-C Approaches) Program
FAA	- Federal Aviation Administration
FCC	- Federal Communications Commission
GRI	- Group Repetition Interval
IIC	- Investigator in Charge
ILS	- Instrument Landing System
LAT/LON	- Latitude/Longitude
LPW	- Loran-C Planning Work-Group
LSES	- Loran Site Evaluation System
NAS	- National Airspace System
NASAO	- Nat'l Association of State Aviation Officials
NDB	- Non-directional Beacon
NFOLDS	- Nat'l Field Office for Loran Data Support
NOTAM	- Notice to Airmen
OBS	- Omni-Bearing Selector
PLC	- Power-Line Carrier
RMMS	- Remote Maintenance Monitoring System
RNAV	- Random (or Area) Navigation
SNR	- Signal-to-Noise Ratio
TD	- Time Difference
USCG	- United States Coast Guard
VOR	- VHF Omni Range
WGA	- Wild Goose Association; Loran-C Navigation Forum